

# Mangawhai-Pakiri : Sustainability of Coastal Sand Extraction From A Near-Shore Bar

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**SUMMARY:** Beach foreshore profile monitoring is often utilised to determine whether a beach is eroding or accreting. For beaches which cycle sediment between the foreshore and the near-shore bar, such assessments cannot be carried out with any degree of certainty without understanding of the coastal processes and sediment movements applicable to the location. A vital component of this is an investigation into the relationship between measured changes in foreshore sand volumes and the occurrence of significant onshore storm events. Post-storm beach rebuild can then be estimated and subtracted from the monitoring results thus allowing a more accurate assessment of net foreshore sediment surpluses or deficits. The above procedure is presented here and was used in a study to determine short-term sustainable limits for sand extraction from the near-shore bar of Mangawhai and Pakiri Beaches on the Northland East Coast of New Zealand.

## 1. INTRODUCTION

In all areas of resource management the words "sustainable use" are gaining increasing and justifiable importance. In New Zealand the advent of the Resource Management Act in 1991 increased the focus on sustainable use of resources, and presented resource managers with the task of preparing management plans for particular resources which invariably require assessment of the size of the resource and sustainable limits for its use. This is often particularly difficult in the coastal environment because of its dynamic nature, where the presence of a resource and fluctuations in its abundance are determined by a large number of factors including fluctuating climatic and environmental influences.

One such coastal resource traditionally used with only limited knowledge of its abundance is the extraction (or mining) of coastal sands. Coastal sands are used for a variety of purposes including manufacture of glass, steel and concrete and are mined from various locations within the coastal system (e.g. from dune to offshore deposits).

Traditional methods of determining the resource abundance involve physical measurement of its extent and the preparation of a "sediment budget" involving assessment of all sediment inputs to and outputs from the sand resource. When the resource is substantially offshore and inputs/outputs are complicated, preparation of a reliable sediment budget often involves extended study using sophisticated and sometimes expensive

techniques. When time or resources do not permit a thorough investigation of the sediment budget, the overall health (or wealth) of the resource may be determined by measuring fluctuations in the principal storage component of the resource system. In the case of shoreface sand deposits this principle storage location is the beach and dune system. Correct interpretation of the measured fluctuations in the resource requires knowledge and understanding of variations in the principle factors effecting the resource supply, whatever these may be. Without this knowledge incorrect assumption on the resource abundance may result.

This paper briefly discusses morphodynamic beach behaviour, levels of beach monitoring and philosophy and assumptions made when interpreting results to determine shoreface sand resource health from measurement of beach and dune profiles. It includes a summary of a case study in which these methods were used to assess short term sustainable limits for sand extraction from the near shore bar of the Mangawhai-Pakiri beach system on the Northland East Coast of New Zealand.

## 2. BEACH PROFILE DYNAMICS AND SEDIMENT MOVEMENT

Characteristic morphological components of a coast are shown in Figure 1 (Fahy, Greenwood and Hilton, 1992).

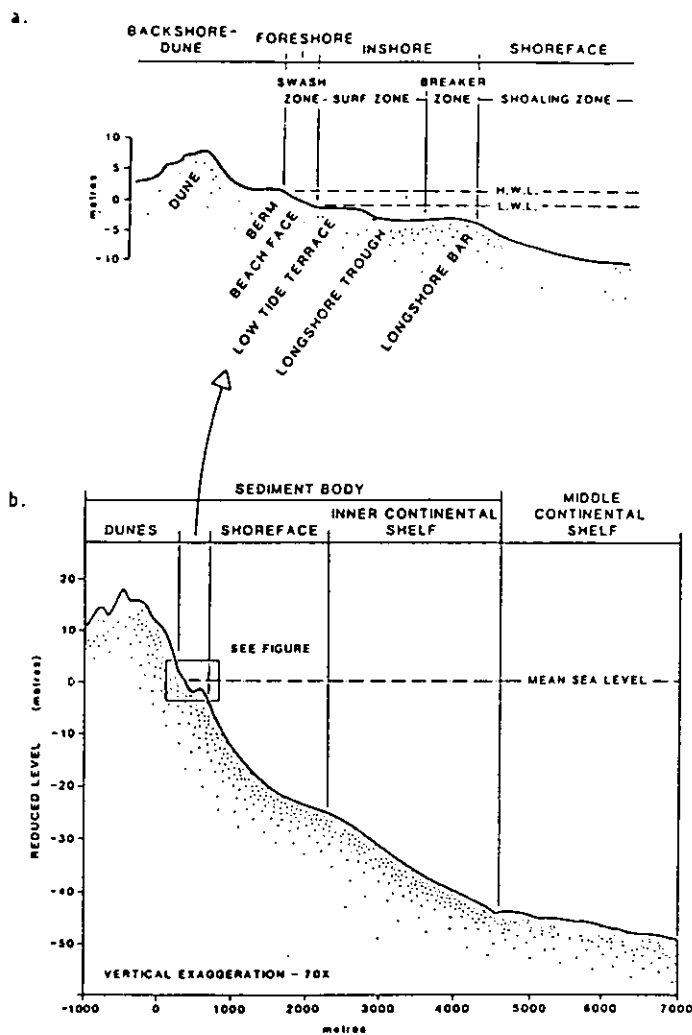


Figure 1: Characteristic morphologic components of the (a) coast and (b) coast, shoreface and continental shelf, Pakiri Bay (Original source Hilton 1990)

Beach profiles are dynamic and adjust to absorb wave energy during storms by the erosion of beach sand, and often dune sand, which is transported offshore until bottom water velocities allow deposition. This forms a nearshore bar which eventually grows to the point that storm waves are forced to break on the bar and expend part of their energy before reaching the beach. The flattened beach profile then absorbs the remaining wave energy without further erosion. This mode of beach profile is known as the dissipative form and is shown as Profile C on Figure 2.

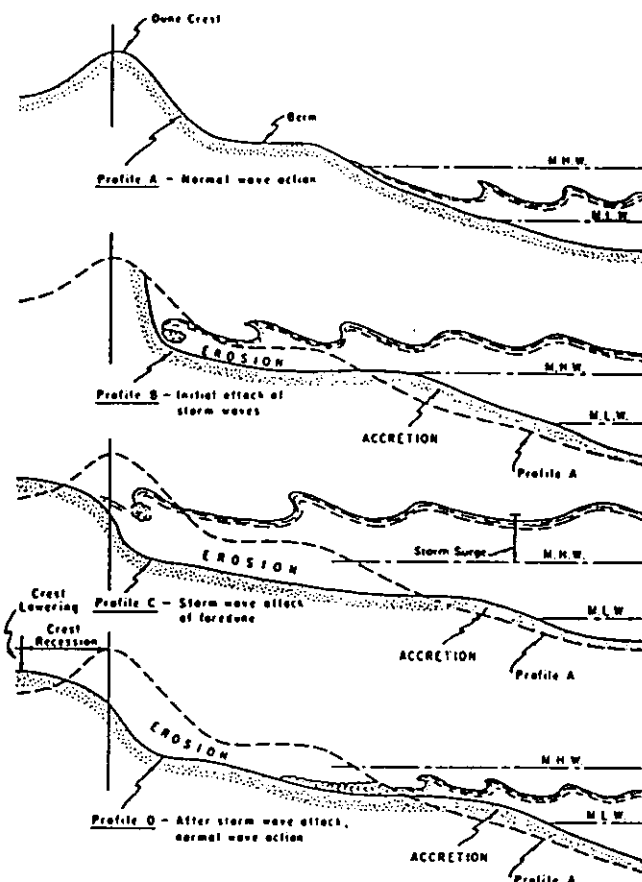


Figure 2: Schematic diagram of storm wave attack on beach and dune. (Coastal Engineering Research Centre 1984)

During quiet sea conditions flatter longer period ocean swells partially break down the nearshore bar system and transport the sand back to rebuild beach storage volumes. As the sand dries wind reinstates dune damage and the beach adopts the steeper more reflective profile shown as Profile A on Figure 2.

A number of intermediate beach modes have been identified by various authors, and the extent to which particular beaches cycle between various model states depends on several variables. All beaches change their model state to some extent and exhibit fair-weather and foul-weather profiles.

This behaviour becomes important when interpreting monitoring profiles. Monitoring is often confined to the tidal and foredune areas of the beach system for practical and economic reasons. In such cases, it is not possible to accurately interpret the short to medium term profiles without some knowledge of the amount of sediment cycled between the beach and the

nearshore bar and of climatic condition and sea states prior to each monitoring survey.

When determining sustainability of sand extraction based on profile monitoring results, littoral drift processes should also be considered, and evaluated where possible.

### 3. BEACH MONITORING

Beach monitoring is required in many cases for informed coastal management, not merely to monitor resource use effects. In many cases beaches may be suffering net erosion due to sediment supply fluctuation (e.g. river catchment changes), which once the extent of erosion is determined will allow informed management decisions to be made. In the majority of situations the primary goal of monitoring is to determine whether the beach is eroding or accreting.

Historic aerial photographs are valuable in general terms. Their use, in most cases, should be limited to approximate qualitative assessments only due to difficulty in determining beach sand contours and hence plan shifts in contours. They are most useful when they show shifts in hard features such as dune toes or faces. When conditions permit they also give valuable information of beach modal condition by showing the presence of and features at nearshore bar systems.

Boundary and historic legal surveys are also useful. In a beach situation these suffer as they often only survey the plan position of a single contour or feature and changes in this plan position can give a false representation of changes in the beach as a whole. Both historical survey and aerial photography are useful in identifying general changes prior to more detailed monitoring.

A superior method is to survey a number of beach cross sections in defined repeatable locations and to resurvey the same section locations at regular intervals and as beach changes dictate. The number, extent and frequency of surveying will depend on site specific restrictions, manpower, finances, and in some cases, (particularly offshore monitoring) apparatus restrictions. Results from these surveys should be plotted graphically as sectional changes and as "excursion" distance changes against time for each cross section.

Excursion changes may be either in terms of selected horizontal distances from the section reference point (plan) for given elevations, or selected elevations i.e. contour values, for the period of records.

### 4. MANGAWHAI-PAKIRI BEACH MONITORING

Mangawhai and Pakiri Beaches on the Northland East Coast of New Zealand are gently curving sandy beaches between Bream Tail and Cape Rodney (as shown on Figure 3). The beaches are separated by Te Arai Point and represent a total length of sandy coast of approximately 25 km.

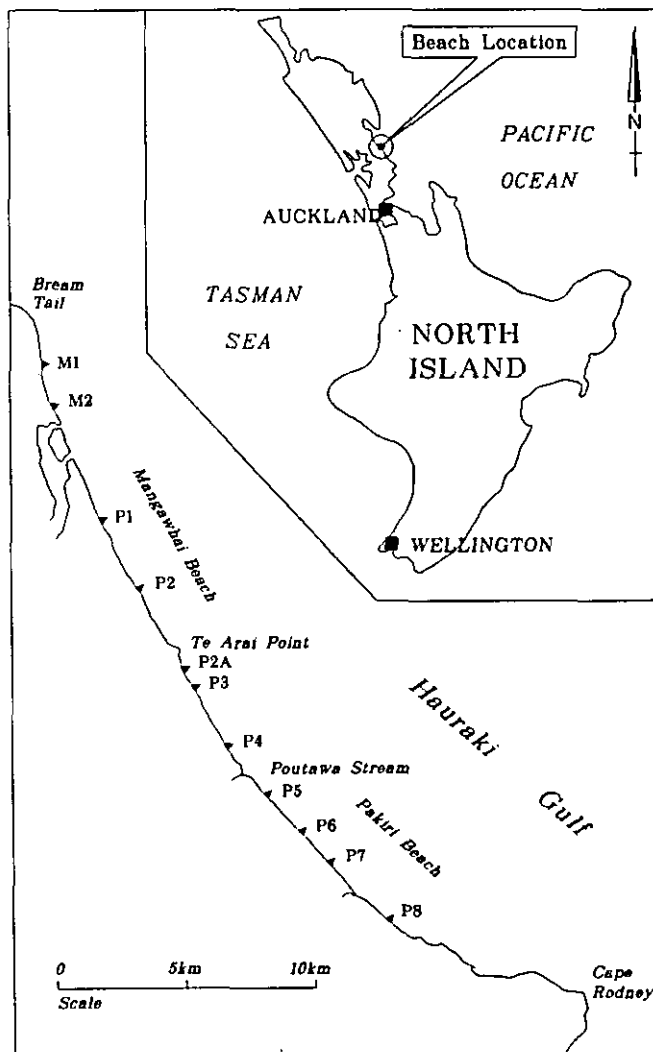


Figure 3: Location map of beach profiles Mangawhai and Pakiri Beaches (From Smith and Ovenden 1992)

Mangawhai Harbour is a very dynamic dual inlet harbour some 2.5 km south of Bream Tail. Only the northern harbour inlet existed prior to 1978, however, in July 1978 severe onshore storms broke through the harbour barrier spit to form the southern (and now dominant) harbour inlet. Following this event concern for the entire Mangawhai-Pakiri beach system prompted beach profile monitoring to begin at the 8 monitoring locations marked P1 to P8 on Figure 2. Profile locations P2A, M1 and M2 were added subsequently and have been surveyed for a much shorter period.

The extent of each profile generally includes the face and toe of the foredunes down to approximately low water level (zero chart datum). The frequency of early monitoring was spasmodic and some monitoring record in the mid 1980's unfortunately appears to have been lost, however, since 1989 frequent 6 monthly surveys have been carried out with additional surveys as necessary.

#### 4.1 Presentation of Results

Results from surveys of each monitoring location can be plotted to show the beach profile at the time of survey and changes in beach profile from previous surveys. (See Figure 4, from Tonkin & Taylor 1992).

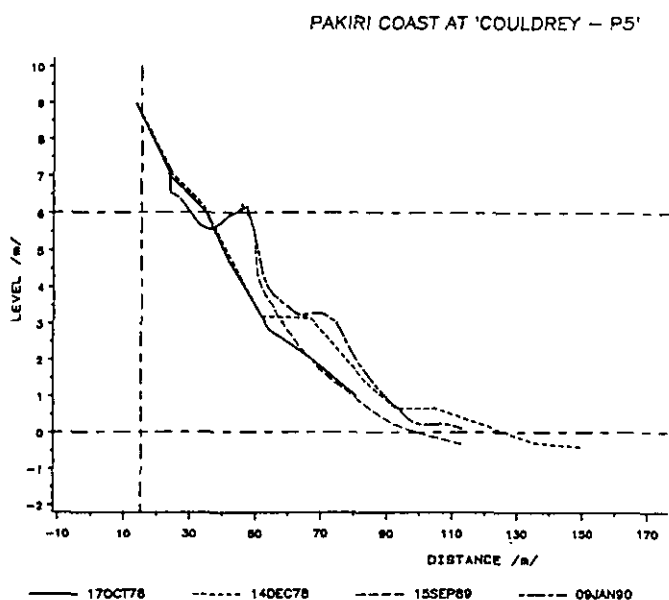


Figure 4: Monitoring Surveys for Cross-Section P5

Increasing numbers of surveys shown on the one graph confuses the picture and the most effective way of viewing the results of many surveys is from excursion distance graphs (see Figure 5, from Tonkin & Taylor 1992), which result from excursion distance analysis. This involves plotting the plan location at each contour from a defined point (i.e. excursion distance), against time.

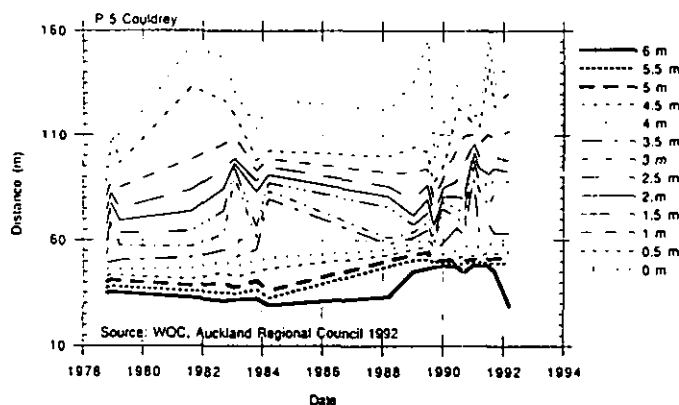


Figure 5: Excursion distance plots for monitoring location P5

#### 4.2 Analysis of Results

By measuring the area of sand on the profile graph between the contours of 0.0 and 6.0 and from the reference location zero beach sand volumes are compared between each survey. This can then be developed to estimate beach sand volumes for the entire length of beach by considering each profile site as presenting half the length of beach to the next site.

However, in interpreting volume changes, the timing of each survey in relation to wind and wave conditions becomes critical.

#### 4.3 Climatic Monitoring

Meteorological and wave rider buoy monitoring over the beach profile monitoring period will give the best indication of environmental conditions. For this study wave rider buoy results were not available, however, wave surge and wind run records from the University of Auckland Marine Laboratory at Leigh provide the most useful data. Review of this data showed that above average onshore stormy conditions were experienced in 1978, 1985 and 1989. The effect of the 1989 storm can be clearly seen in the excursion distance analysis (see Figure 5) where large amounts of sand were taken from the beach to the nearshore bar

causing the excursion distance of each contour in the beach zone to be reduced. Post storm beach volumes are replenished as sand is transported from the longshore bar back to the beach. Most erosion damage occurs during brief extreme events rather than extended period of only slightly above average onshore conditions.

### 5. BEACH VOLUME CHANGES

An additional profile survey took place at Mangawhai-Pakiri within days of the August/September 1989 storms, which consequently included very little post-storm rebuild of beach sand volumes. Post-storm recovery of the beach is dependent on environmental conditions during the recovery period. Under constant offshore conditions beach volume recovery would be expected to be greater in the initial recover period tapering off to the point where the nearshore bar was broken down and the typical beach fair-weather profile was reached.

When the period of monitoring covers several significant storm events of equivalent magnitude over a period of time, beach volumes would be expected to fluctuate as shown in : Figure 6(a) for beaches in net accretion, Figure 6(b) for stable beaches, and Figure 6(c) for beaches in net erosion.

The rate of net accretion or erosion can then be determined by calculating:

$$\frac{\Delta v}{\Delta t}(\text{for } t_1) = \text{net rate of change of beach volume}$$

- where
- $\Delta v$  = change in beach sand volume for points at time  $t_1$  from significant storm events
  - $\Delta t$  = change in time for points at time  $t_1$  from storm events
  - $t_1$  = arbitrarily selected time interval following each storm event

This form of analysis is particularly important for beaches which cycle between various modal states (as most exposed beaches do), and where net beach volume change is thought to be small, as comparison of beach volumes between surveys with no reference to storm history can result in misleading conclusions. For example if beach volumes were compared at time  $t=0$

and time  $t=5$  years, Figure 6(a) would yield an inflated assessment of net accretion, and Figures 6(b) and 6(c) would both indicate that the beach was accreting when in fact it is stable and eroding respectively.

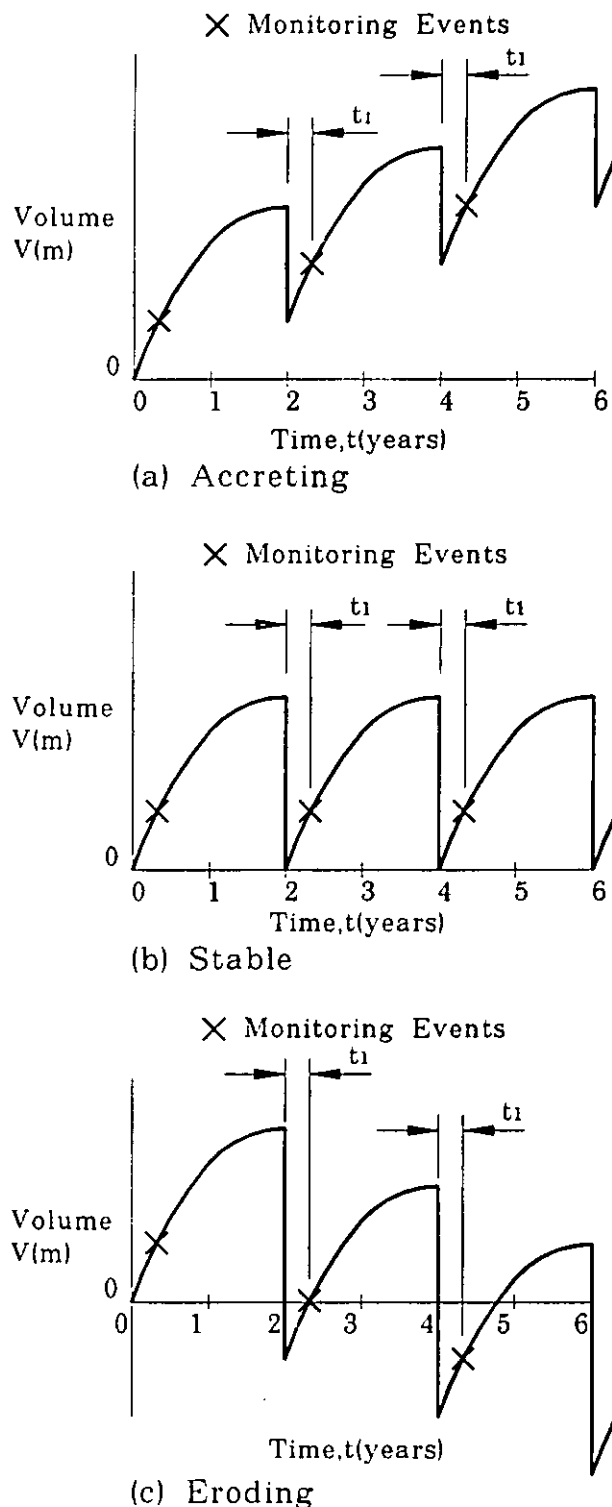


Figure 6: Beach Volumes (v) versus time (t)

The greatest accuracy of results will be achieved if time interval  $t_1$  is reduced to a minimum. This is because the rate of post-storm build is dependent on post-storm climate conditions which will undoubtedly vary introducing a further uncertainty. Accuracy will also be increased if  $\Delta t$  is taken as large as possible.

Of course in reality significant storms of equivalent magnitude are unlikely to occur within a short monitoring time frame. Assumptions and approximations are therefore required to allow for varying magnitude storms, however, if the above principles are applied, post-storm rebuild can be estimated out of beach volume change calculations, resulting in greater accuracy in calculating net long term erosion or accretion rates.

## 6. MANGAWHAI-PAKIRI ANALYSIS

The above procedure was used for the first known time for the Mangawhai-Pakiri Beach system to estimate net volume change with results presented in Tonkin & Taylor (1992), and summarised below. The two significant storms focused on in the analysis were in July 1978 and August/September 1989.

It should be noted that the 1978 storm is believed to have been greater in magnitude than the 1989 storm although relative magnitudes have not been determined in detail. There is also a further complication in that during the entire monitoring period sand was being mined from the seaward slope of the nearshore bar in approximately the central third of the combined beach system. This has been allowed for in the calculations.

Monitoring in September and October 1978 occurred two to three months after the July storm events. Observing beach profile plots for P3, P7 and P8 shows initial post storm rebuild in the middle and lower beach levels. September 1989 profiles were taken within days of the August/September stormy period while the January 1990 profile was taken approximately four months following the August/September storms. All September 1989 profiles show typical storm scoured dissipative beach forms while all January 1990 profiles show significant post storm beach build. The relative degree of beach build evident in the September/October 1978 profiles lies somewhere between beach shapes recorded in the September 1989 and January 1990 monitoring. This would be expected based on the relative time lags between storm events and

each set of monitoring.

Averaging beach volumes recorded in September 1989 and January 1990 monitoring and comparing these to beach volumes recorded in the September/October 1978 monitoring will therefore give the best approximation of  $t_1$  and the best available estimate of net long term sand accumulation in the Mangawhai-Pakiri sand system.

The following Tables 1 and 2 summarise this analysis.

Site	Sept/Oct 78 to Sept 89 (m <sup>3</sup> /m of beach)	Sept/Oct 78 to Jan 90 (m <sup>3</sup> /m of beach)	Average (m <sup>3</sup> /m of beach)
P1	-38	45	3.5
P2	6	42	24
P3	38	47	42.5
P4	27	53	40
P5	20	65	42.5
P6	-11	20	4.5
P7	34	73	53.5
P8	-27	-6	-16.5

Table 1  
Net Volume Change on  
Mangawhai-Pakiri Beach  
(+ve values represent net accretion)

All changes in beach volumes in Table 1 are calculated between levels of zero and 6 m and are based on profiles provided by the National Institute of Water and Atmospheric Research (NIWAR) in Hamilton, New Zealand.

Annual extraction rates averaged 63,100 m<sup>3</sup> per annum for the 11 year period from 1978 to 1989. To estimate total net sand build the change in volume for each transect was multiplied by the length of beach (see Table 2).

Location of Profile	Shoreline Length (km)	Average Volume Change (From Table 1) (m <sup>3</sup> /m)	Net Sand Accumulation (m <sup>3</sup> )
P1	3.65	3.5	12,775
P2	3.65	24	87,600
P3	3.325	42.5	141,312
P4	2.275	40	91,000
P5	2.6	42.5	110,500
P6	2.1	4.5	9,450
P7	2.25	53.5	120,375
P8	2.8	-16.5	-46,200

Table 2  
 Net Sand Accumulation for the  
 Mangawhai-Pakiri Beach  
 (From Sept/Oct 1978 Monitoring)  
 (Positive values represent net accretion)

Net long term accretion north of Mangawhai Heads was estimated as the average of the other profiles as follows:

$$1600 \text{ m} \times 24 \text{ m}^3/\text{m} = 38,400 \text{ m}^3$$

Therefore total estimated long term accretion for the 11 year period from 1978 to 1989 is:

$$526,812 \text{ (From Table 2)} + 38,400 = 565,212$$

This is equivalent to an average net annual sand build for the entire beach of 51,382 m<sup>3</sup>. Locations P3 and P4 also include a considerable increase in dune storage above the beach level of 6 metres. The recent monitoring does not completely define the dune shape above 8 metres. However, it would appear that an additional 30,000 m<sup>3</sup> has been stored in this area per annum. Combine these with average extraction over the period of 63,100 m<sup>3</sup>, results in the average total annual net accretion of approximately 140,000 m<sup>3</sup> per annum.

Excursion distance analysis and profile graphs show that the majority of this average annual net sand surplus is being stored in the foredune area of monitoring locations P3 to P7.

Contours in the lower foreshore area do not exhibit any discernible change from post 1978 storm position to post 1989 storm position. Given a continuation of the measured net sand surplus in the system, lower foreshore contours, and consequently the near-shore bar and shoreface would be expected to pro-grade. Within the limits of the survey information available evidence to date of lower foreshore and shoreface accretion is inconclusive at Mangawhai-Pakiri.

## 7. COASTAL MANAGEMENT DECISIONS

For many coastal management decisions the ability to conclude whether a beach is eroding or accreting and at what approximate rate is sufficient.

In the case of setting sustainable limits for sand mining from a nearshore bar the situation is complicated by the fact that the monitoring does not include the nearshore bar, or shoreface seaward of the nearshore bar. It is reasonable to assume, where the net sediment surplus is being supplied primarily from onshore movements from the inner continental shelf to the shoreface (as is the case for Mangawhai-Pakiri Beaches), that any measured shift in the total beach profile position will be representative of equivalent shifts in position of the nearshore bar and the shoreface seaward of the nearshore bar. As discussed above at Mangawhai-Pakiri the lower foreshore is not yet exhibiting a discernible permanent shift and any assumptions made in the short term regarding possible additional resource in the shoreface area would need to be confirmed by extending monitoring to include this area before long term limits for sustainable extraction could be set.

It should, however, be recognised that where permanent foredune growth is being experienced there is probably some accretion in the shoreface area and that analysis of foreshore monitoring profiles are likely to underestimate the net sand surplus in the total system. When sustainable limits are to be determined based solely on foreshore surveys a factor of safety should be applied to the calculated net sand surpluses.

Appropriate factors of safety should be chosen following consideration of all variables affecting the calculated result including the following:

- knowledge of coastal processes at the site, including littoral drift
- accuracy of survey techniques
- extent of survey profiles and probability of over estimating or underestimating the resource due to profile limits
- equivalence of reference storms
- time span of monitoring
- return period of reference storms and periodicity of overall weather patterns
- possible future changes on sediment inputs e.g. river catchment changes, updrift dredging works etc.

General rules to fit all situations are not available at present as many variables require site specific evaluation. In all cases judgement will need to be exercised with the greater the knowledge of a particular system, and the higher the return period of monitored storms, the lower the selected factor of safety likely to be necessary.

## 8. CONCLUSIONS

Coastal management decisions are particularly difficult due to the dynamic nature of the coastal system and fluctuations in climatic and environmental forces influencing the coast. Most coastal management decisions involving beaches revolve around assessment of whether the beach is eroding, stable or accreting.

For beaches which cycle between several modal beach states, beach profile surveys which extend only to low water must be interpreted in relation to historic storm data to minimise the effects of sand movements to and from the nearshore bar attributable to climatic induced

modal change.

If this is done, beach profile surveys over an extended time period covering several significant onshore storms then become an effective system to assess current beach erosion.

Short term limits on sand extraction from a nearshore bar may be determined by application of an appropriate factor of safety, with lower factors of safety being applicable where monitoring surveys the effects of high return period storms, and other variables have been determined with some confidence.

## 9. ACKNOWLEDGEMENTS

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